



SSD95D0069
Vol. 1

Executive Summary
Structural Arrangement Trade Study
Reusable Hydrogen Composite Tank System (RHCTS)
and
Graphite Composite Primary Structures (GCPS)
Cooperative Agreements NCC8-39 and NCC1-193

March 14, 1995

Prepared for:
NASA
Marshall Space Flight Center
Langley Research Center
Ames Research Center



 **Rockwell Aerospace**
Space Systems Division

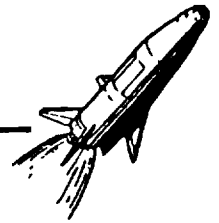
NORTHROP GRUMMAN

 **Rockwell Aerospace**
North American Aircraft

 **HERCULES**

Briefing Objectives

SSTO



To present the Trade study process, requirements used, analysis performed, and data generated

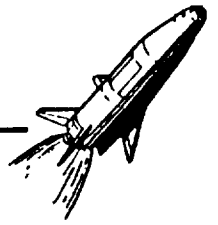
To present the derived Conclusions and Recommendations

Through understanding of the above arrive at NASA/RI cooperative team joint decisions pertaining to TA 1 and TA 2 future structural developments

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Agenda

SSTO

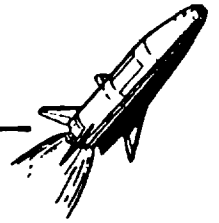


Trade Study Objective
Requirements
Operability Features
Subsystems Supporting Analysis
Structural Arrangement Options
Selection Process
Conclusions and Recommendations

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Trade Study Objectives

SSTO



Determine the most suitable vehicle structural arrangement and structural materials applications recognizing:

The most suitable vehicle structural arrangement contains the most suitable Major Structures, i.e, Hydrogen and LO Tankage concepts, Intertank, wing and Thrust Structure concepts

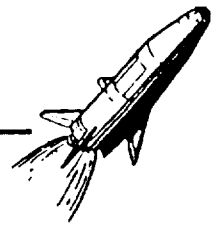
Consider other potential technology development needs

On the basis of the foregoing recommend the Major Structures for continuing development in TA 1 and TA 2

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES
--

Major Requirements/Guidelines Direct Trade Study

SSTO



Requirements

- Satisfy the National Launch needs
 - Space Station Missions
 - Deliver and return payloads/crews to and from 220 nmi circular/51.6° orbit
- Provide high degree of reliability and passenger safety per flight
- Acceptable cost
- Environmentally acceptable (EPA standards, etc.)

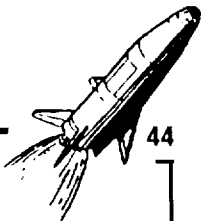
Assumptions

- Capable of delivering/returning 25,000 lb to/from Space Station
- Payload Bay Volume: 15 x 30 ft
- Mission Duration: 2 to 7 days
- Airframe Life: 100 missions/20 years
- OMS Delta V Budget: 1,100 ft/s
- RCS Delta V Budget: 110 ft/s
- Cross Range: 1,100 nmi
- Capable of withstanding rainstorm on launch pad
- Dry Weight Growth Margin: 15%
- Autonomous operations (ground and flight)
- Parallel, off-line processing of payloads
 - Standardized interfaces
- Off-line regularly scheduled depot maintenance

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

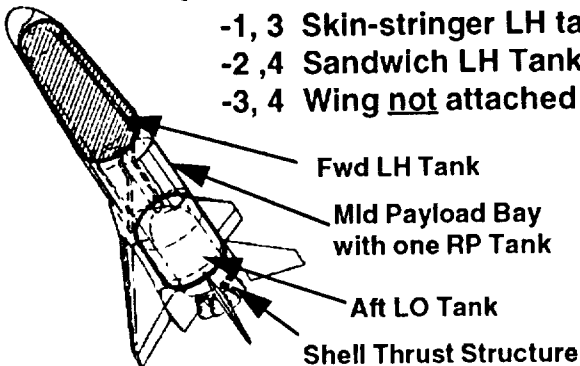
24 Configuration Structural Arrangement Options Studied

SSTO



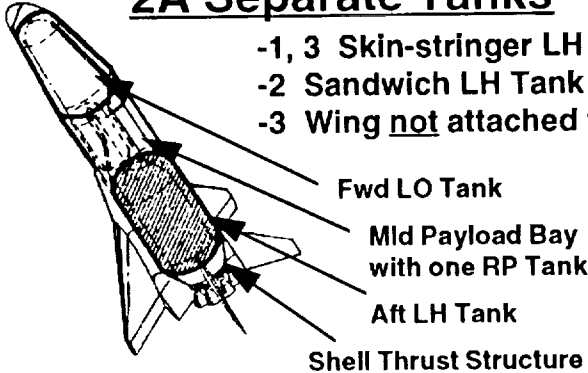
1A Separate Tanks

- 1, 3 Skin-stringer LH tank
- 2 ,4 Sandwich LH Tank
- 3, 4 Wing not attached to LO Tank



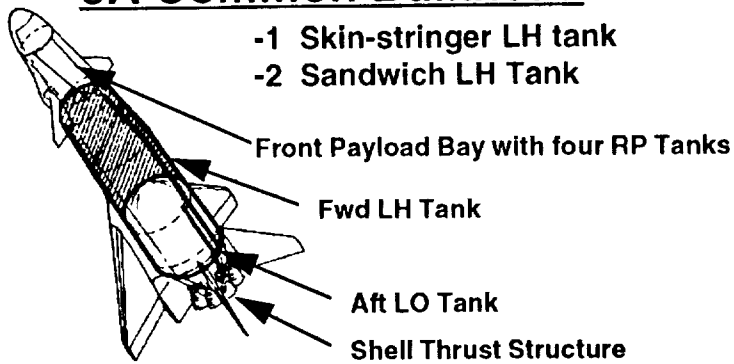
2A Separate Tanks

- 1, 3 Skin-stringer LH tank
- 2 Sandwich LH Tank
- 3 Wing not attached to LH Tank



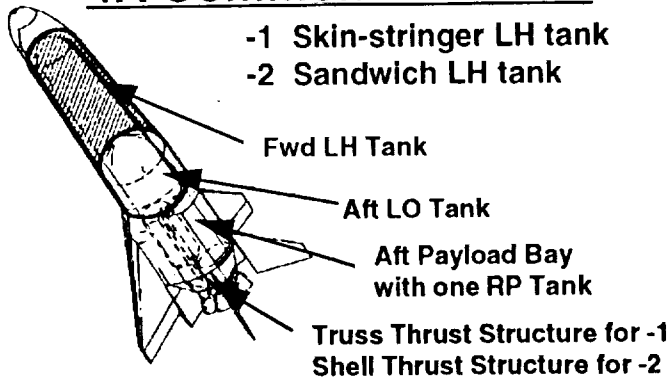
3A Common Bulkhead

- 1 Skin-stringer LH tank
- 2 Sandwich LH Tank



4A Common Bulkhead

- 1 Skin-stringer LH tank
- 2 Sandwich LH tank

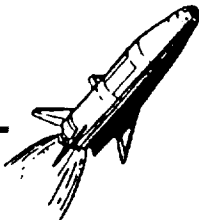


1B-1 and 2B-1 have non-integral (floating) LH tanks.
All LO tanks are integral, skin-stringer-frame construction.

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

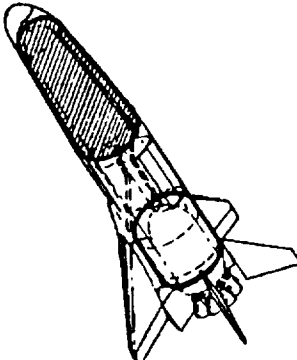
Wide Range of Structural Materials/TPS Options Studied

SSTO



1A-1

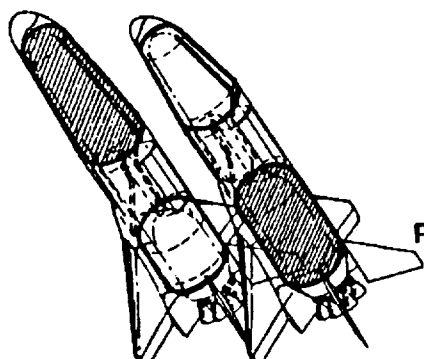
Intertank Option 11



AFRSI or TABI
AFR 700 - Polyimide HC Core
< 550 F

1B-1 and 2B-1

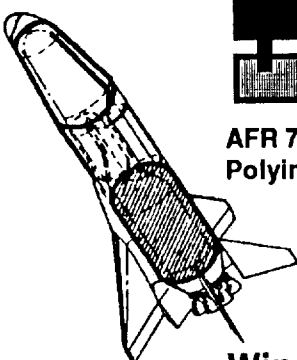
Non-Integral Tank Option 7



AFRSI or TABI
AFR 700 Polyimide HC Core
IM7/977-2
< 550 F
< 250 F
< 250 F

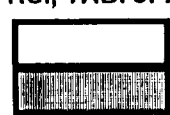
2A-1

Intertank and Wing Option 10



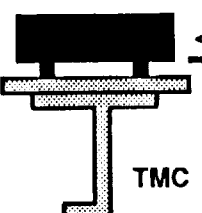
CSIC Panels (Mechanically Attached)
AFR 700 - Polyimide HC Core
< 550 F

Intertank, Wing, Tail and Control Surfaces Option 11



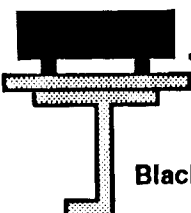
AFRSI, TABI or AETB
AFR 700 - Polyimide HC Core
< 550 F

Wing Option 12



CSIC Panels (Mechanically Attached)
TMC
< 1200 F

Control Surface Option 14



CSIC Panels (Mechanically Attached)
Blackglas
< 1200 F

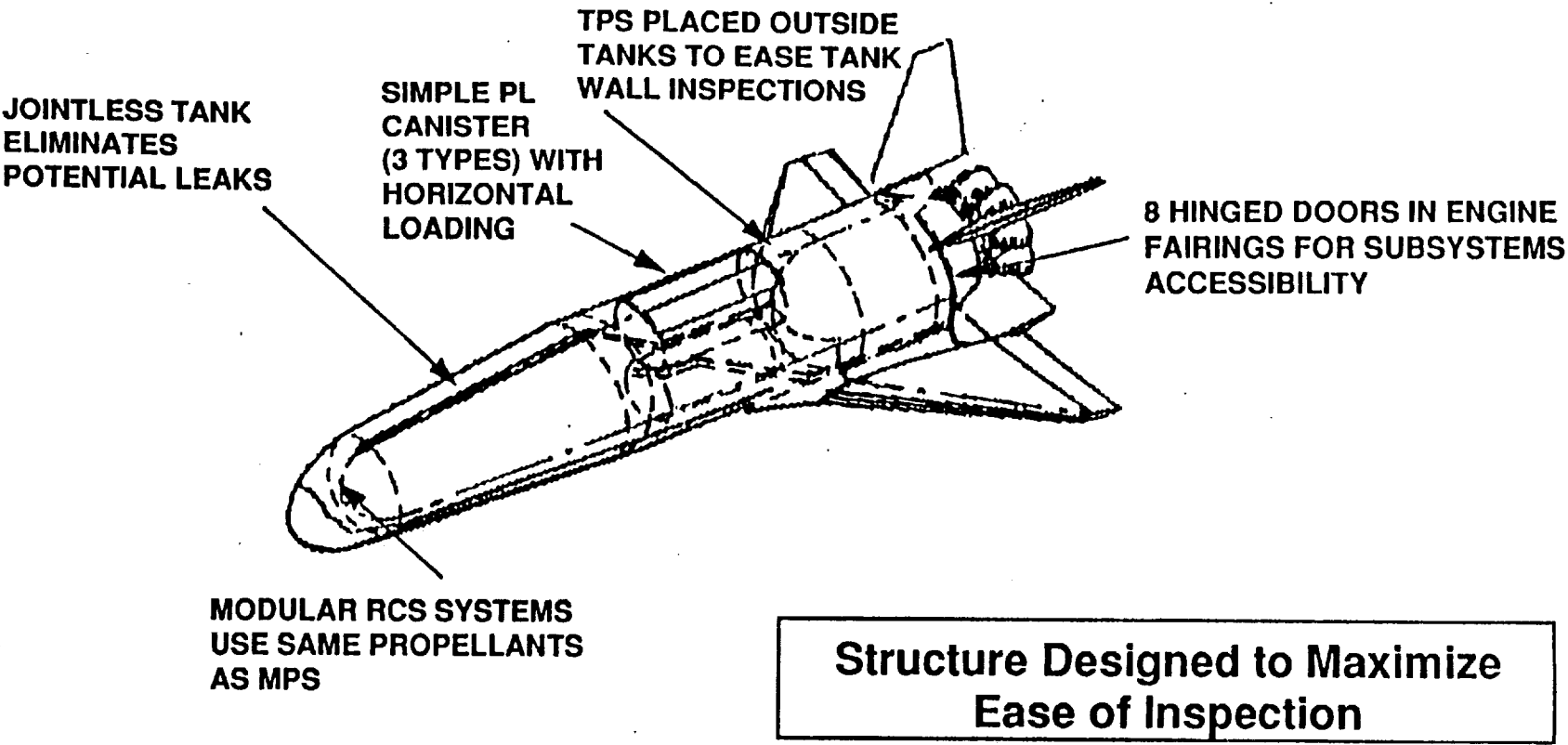
NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Vehicle Design Incorporates Operability Features

SSTO



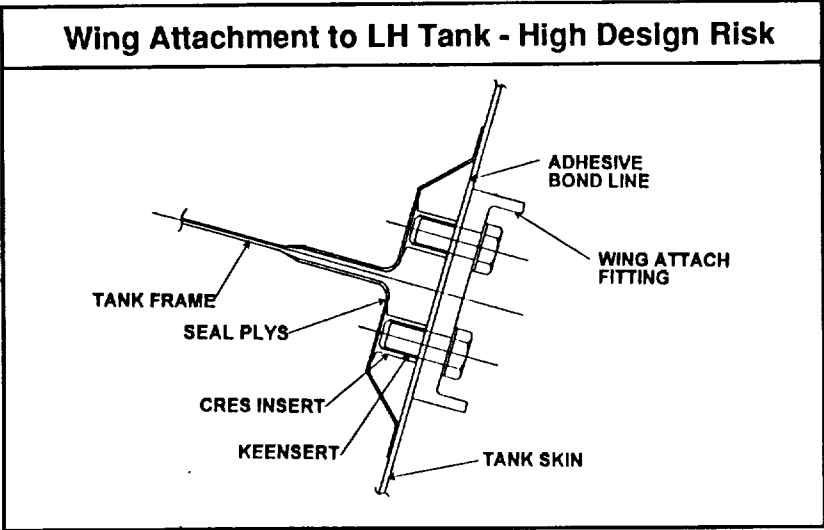
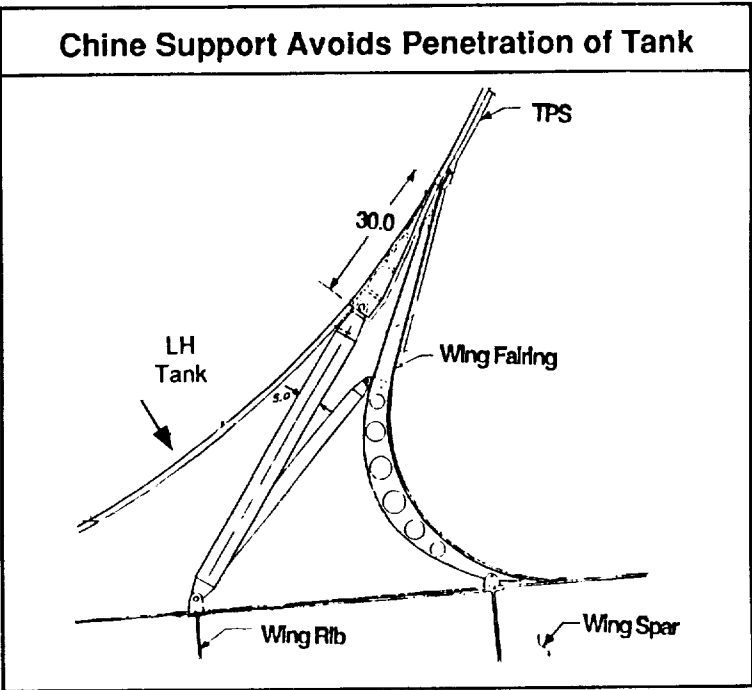
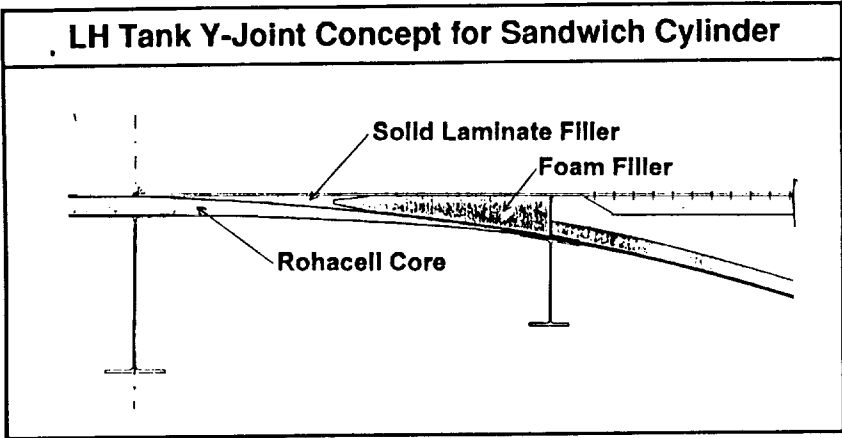
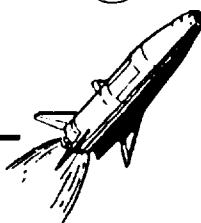
Vehicle Utilizes “Clean Pad”
(No Tower) Approach



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Study Addressed Key Structural Design Details

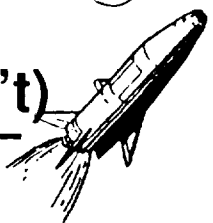
SSTO



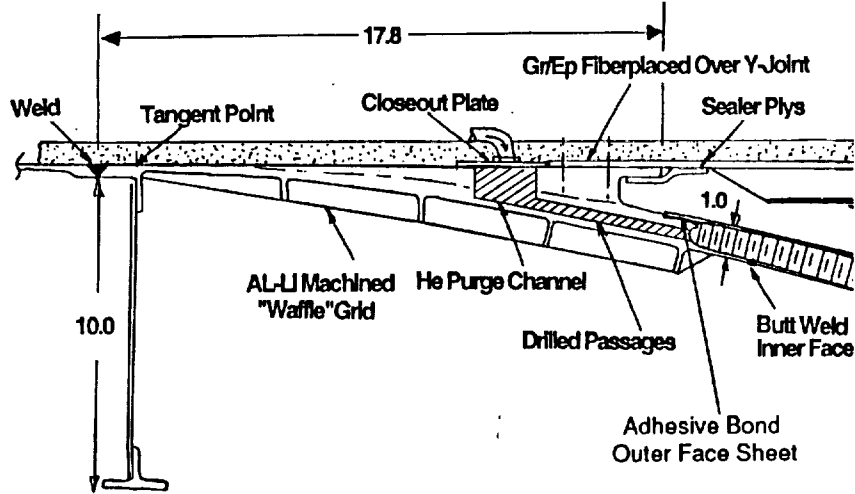
NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Study Addressed Key Structural Design Details (con't)

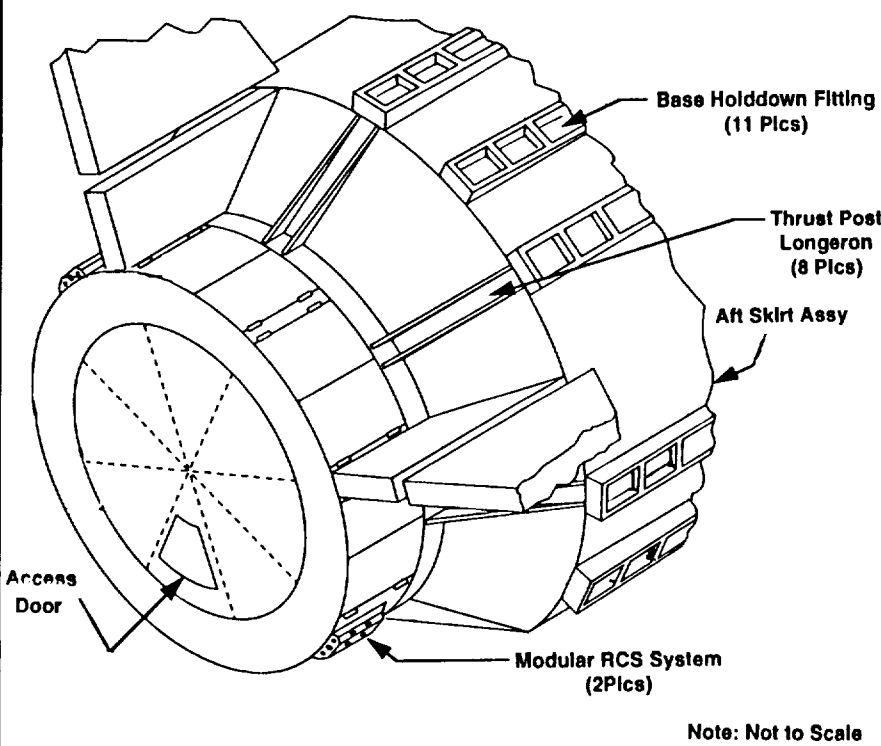
SSTO



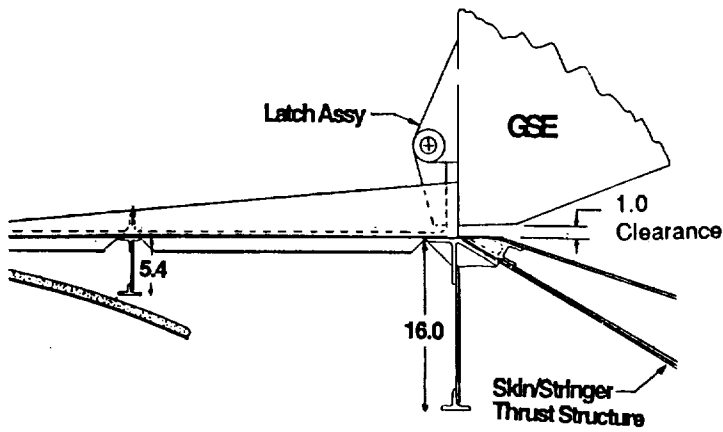
Potential Common Bulkhead Joint Concept



Fairing for Access to Propulsion System



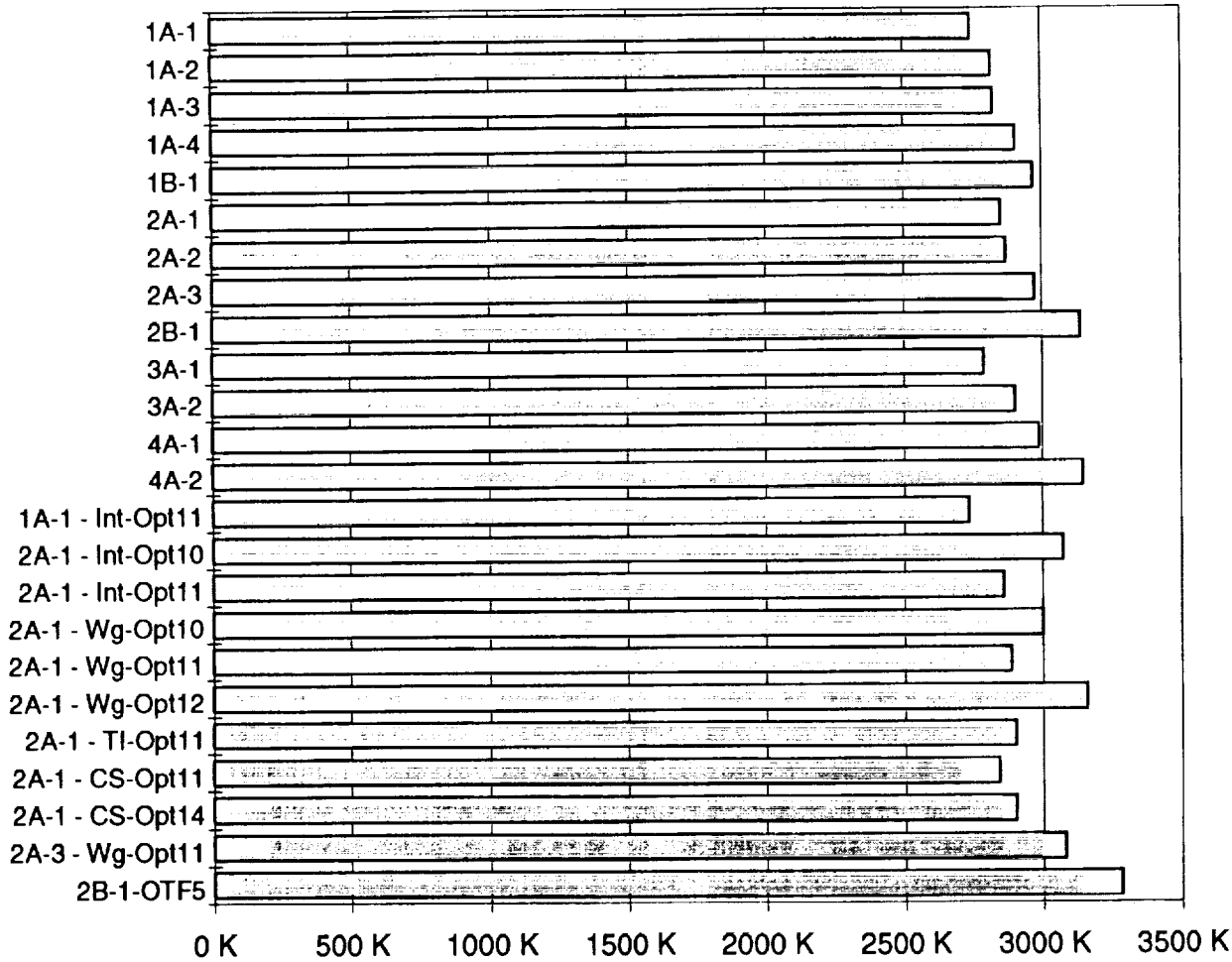
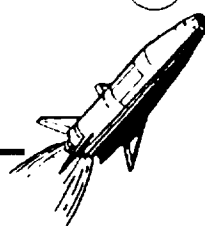
Thrust Structure Hold Down Concept



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

1A-1 and 1A-1 Intertank Option 11 Have Lowest Vehicle Gross Fueled Weights

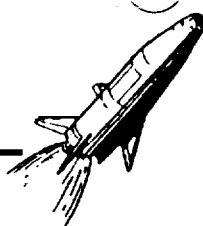
SSTO



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

41 Selection Criteria Are Used

SSTO



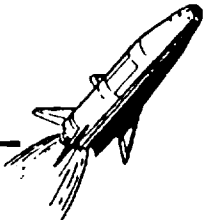
1. DESIGN AND PRODUCTION EFFORT - 10% <ul style="list-style-type: none">a. Certification Effort - 3%b. Verification Effort - 3%c. Producibility Effort - 2%d. IHM Effort - 2%	5) VEHICLE CONTROLLABILITY - 9% <ul style="list-style-type: none">a. Ascent Controllability - 3%b. Hypersonic Controllability - 3%c. Subsonic Controllability - 3%	8) SAFETY - 15% <ul style="list-style-type: none">a. Probability of Tank Penetration - 6%b. Tank Rupture Due To Debris Impact - 4%c. Number of Fracture Critical Parts - 2%d. Probability of LH/LO Contact - 1%e. Amenability to IHM - 2%
2) MISCELLANEOUS WEIGHTS - 6% <ul style="list-style-type: none">a. Primary Structure Weight - 2%b. TPS Weight - 1%c. Total Dry Weight - 3%	6) ON PAD OPERATIONS - 12% <ul style="list-style-type: none">a. Pressurization/fueling Flexibility - 3%b. Sub-Systems For On-Pad Operations - 3%c. Systems Requiring Disconnects - 3%d. Facilities - 3%	9) DEVELOPMENT RISK - 10% <ul style="list-style-type: none">a. Structural Design Risk - 3%b. TPS Design Risk - 3%c. Technology Development - 4%
3) GROSS FUELED WEIGHT - 14% <ul style="list-style-type: none">a. Gross Fueled Weight Sensitivity - 14%	7) MAINTENANCE OPERATIONS - 18% <ul style="list-style-type: none">a. Wide Area Coverage Inspection - 4%b. Localized Area Coverage Inspection - 2%c. Accessibility - 1%d. Number of Inspection Points - 2%e. Re-Waterproofing - 1.5%f. Sustained Personnel - 1.5%g. Turn Around Time - 3%h. Facilities - 1.5%i. Equipment Requirements - 1.5%	10) COST <ul style="list-style-type: none">a. DDT&E Costb. Operations Costc. Production Costd. Life Cycle Coste. Cost Per Flight
4) PROPULSION INTERFACE - 6% <ul style="list-style-type: none">a. Number Of Feed Line Penetrations - 1.5%b. Number Of Propellant Suction Lines - 1.5%c. Ease Of Slosh Baffle Integration - 1.5%d. Ease Of Tank Cleaning - 1.5%		

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

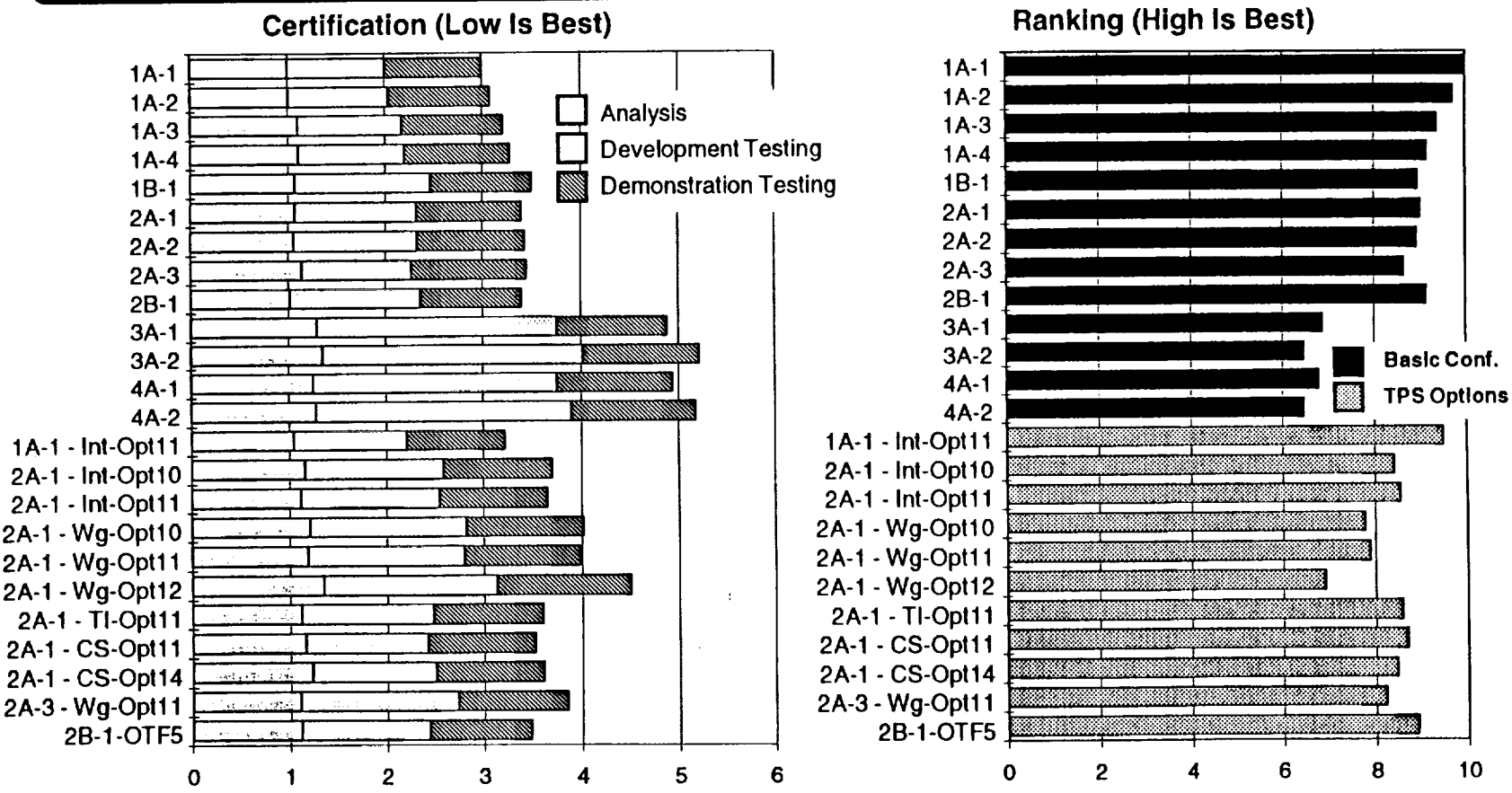
Example Criteria Evaluation

1A Option Ranked Best For Certification Effort

SSTO



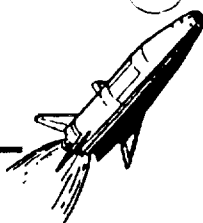
1a. Certification Effort - (Qualitative evaluation) - The candidate vehicle options are rated according to the perceived effort of analysis, development testing, and demonstration testing required for certification of structure and TPS. Certification refers to only the design and is achievable without fabrication of a vehicle.



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Major Categories Summarized To Top Level Chart

SSTO

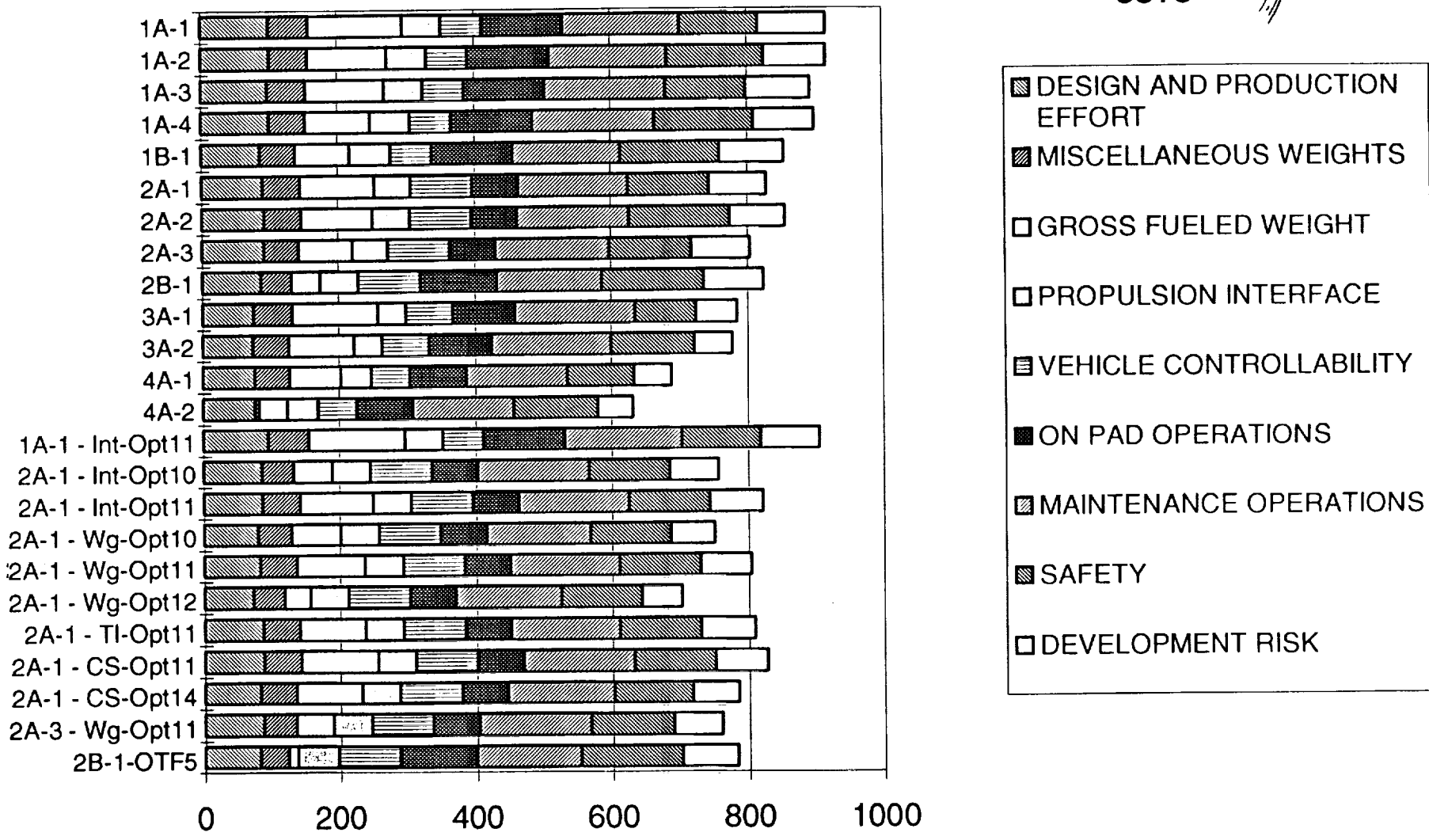
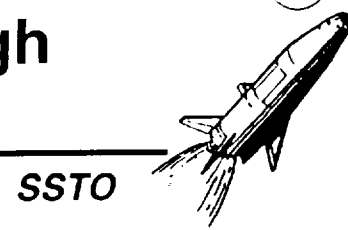


COST - 0%					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
DEVELOPMENT RISK - 10%					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
SAFETY - 15%					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
MAINTENANCE OPERATIONS - 18%					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
ON PAD OPERATIONS - 12%					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
VEHICLE CONTROLLABILITY - 9%					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
GROSS FUELED WEIGHT - 14%					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
PROPULSION INTERFACE - 6%					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
MISCELLANEOUS WEIGHTS - 6%					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
DESIGN AND PRODUCTION EFFORT - 10%					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
Certification Effort		30%		0	
Verification Effort		30%		0	
Producibility Effort		20%		0	
IHM Effort		20%		0	
		100%		0	
Weighted Score			0.00		0

TOP LEVEL RESULTS					
Trade Option #		1A-1		1A-2	
Selection Criteria		Wt	Score	Wt'd	Score
DESIGN AND PRODUCTION EFFORT		10%	0	0	0
MISCELLANEOUS WEIGHTS		6%	0	0	0
GROSS FUELED WEIGHT SENSITIVITY		14%	0	0	0
PROPULSION INTERFACE		6%	0	0	0
VEHICLE CONTROLLABILITY		9%	0	0	0
ON PAD OPERATIONS		12%	0	0	0
MAINTENANCE OPERATIONS		18%	0	0	0
SAFETY		15%	0	0	0
DEVELOPMENT RISK		10%	0	0	0
COST			0	0	0
		100%		0	
Weighted Score			0.00		0

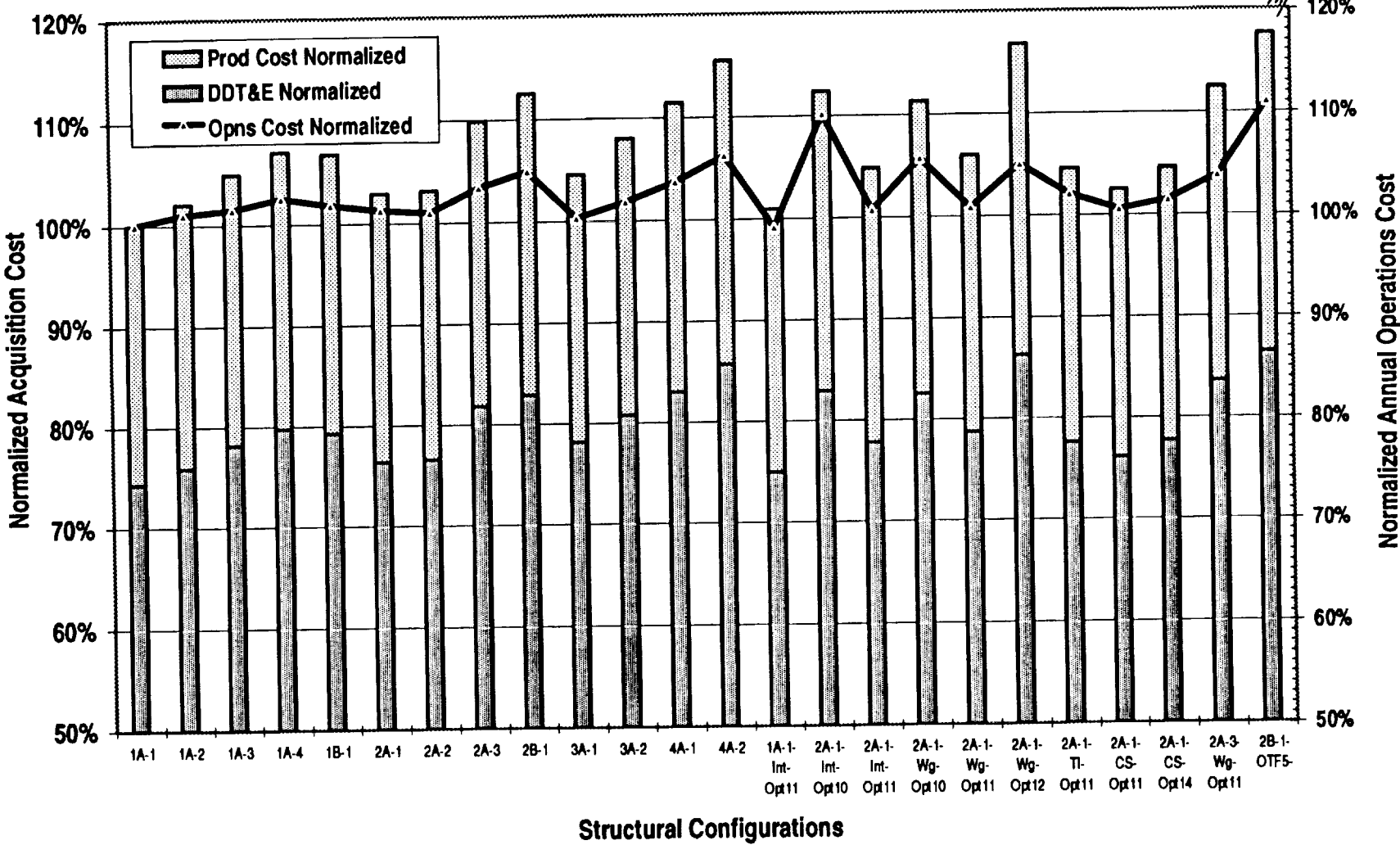
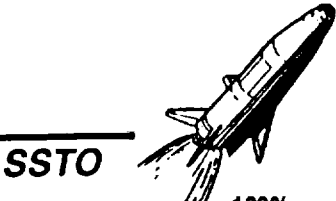
NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

1A Options Received Best Scores Due To High Ranking In Nine Key Areas



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

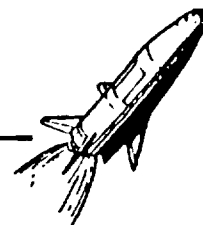
Cost Estimates Favor 1A-1 But 2A-1 and 3A-1 Are Only Slightly Higher in Cost



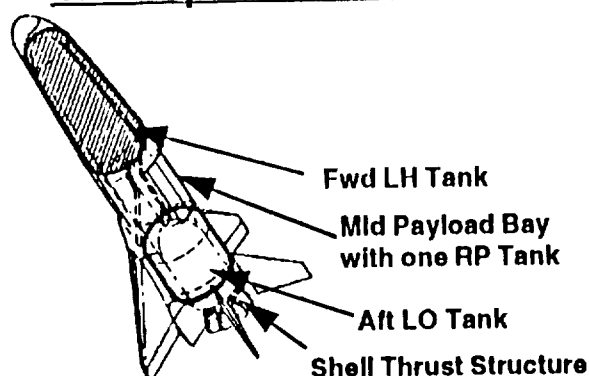
NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

1A Has Most Suitable Structural Arrangement

SSTO



1A Separate Tanks



- Lowest Current Vehicle Gross Weight - Best 1A is 107, 000 lbs lower than 2A-1 and 228,900 lbs lower than 2A-3

- Lowest Vehicle Cost and best in Evaluation

- On pad prepressurization of Hydrogen tank is not required like in 2A

- Hydrogen Tank has no mechanical penetrations (except manhole) - No wing or fairing attachments

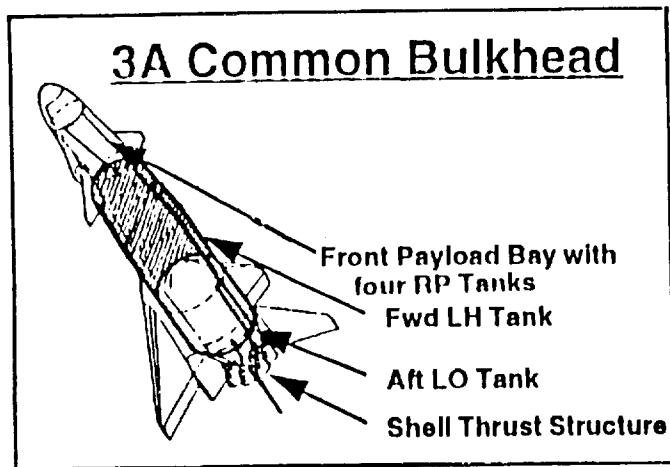
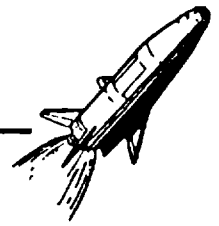
- Hydrogen Tank has lowest skirt Y-joint loading - Significant design advantage

- Avoidance of Wing supports into LO Tank is most easily achieved with small wing glove - Avoidance of LH tank attachment with 2A requires long glove

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

3A Common Bulkhead Design Is Prohibitive Risk - Attractive Wth Intertank Design

SSTO



- 3A-1 - Gross Vehicle Weight is currently only 42,115 heavier than 1A-1 but Common bulkhead design (Al-Li LO tank to Composite LH tank is excessive risk)

- 3A - Common bulkhead design for Composite LH and LO tanks reduces 3A Vehicle weight and design risk - This is significant development effort

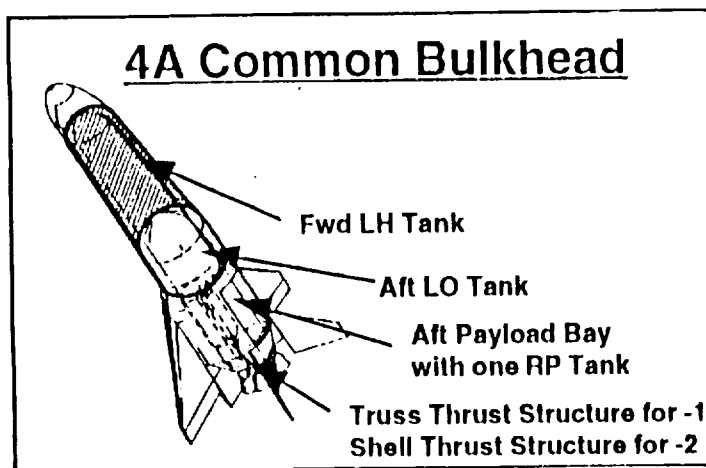
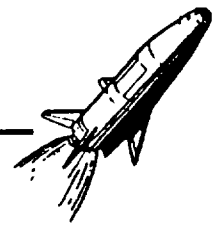
- 3A Modified with Intertank has Gross Vehicle Weight Is 140,000 lbs heavier than 1A-1 but should be more controllable

- 3A Modified has LH tank with no wing or fairing attachments

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

4A Common Bulkhead Design Represents Prohibitive Risk

SSTO



4A-1 - Gross Vehicle Weight is 241,600 lbs heavier than 1A-1 but Common bulkhead design (Al-Li LO tank to Composite LH tank is excessive risk)

- 4A - Common bulkhead design for Composite LH and LO tanks reduces 4A Vehicle weight and design risk - This is significant development effort

- Cost is higher than 1A-1

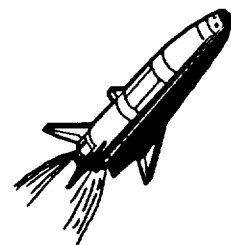
- 4A - Expected advantage of avoidance of wing attachment to cryogenic tankage is achievable with 1A and 3A

- 4A - Highest exposed tank surface for debris impact

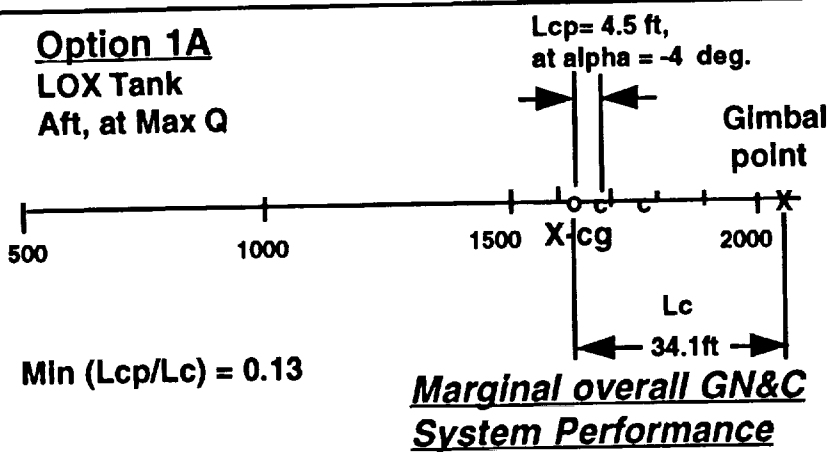
NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Preliminary Tri-Propellant Assessment Indicates That Option 1A is Marginally Controllable and Option 2A is Stable and Controllable

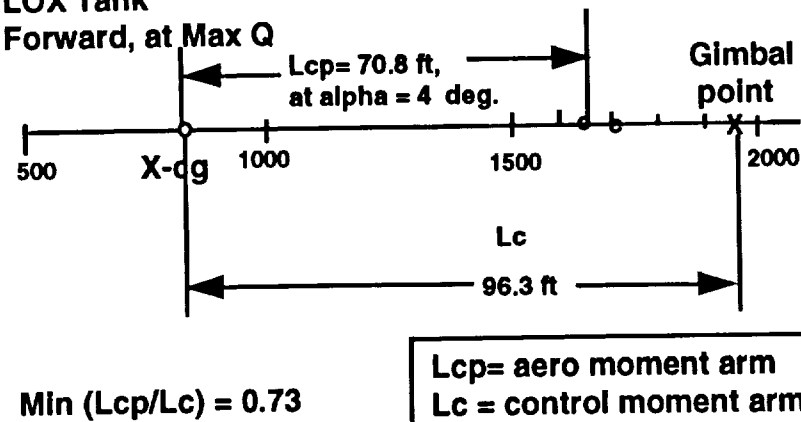
SSTO



Option 1A LOX Tank Aft, at Max Q



Option 2A LOX Tank Forward, at Max Q

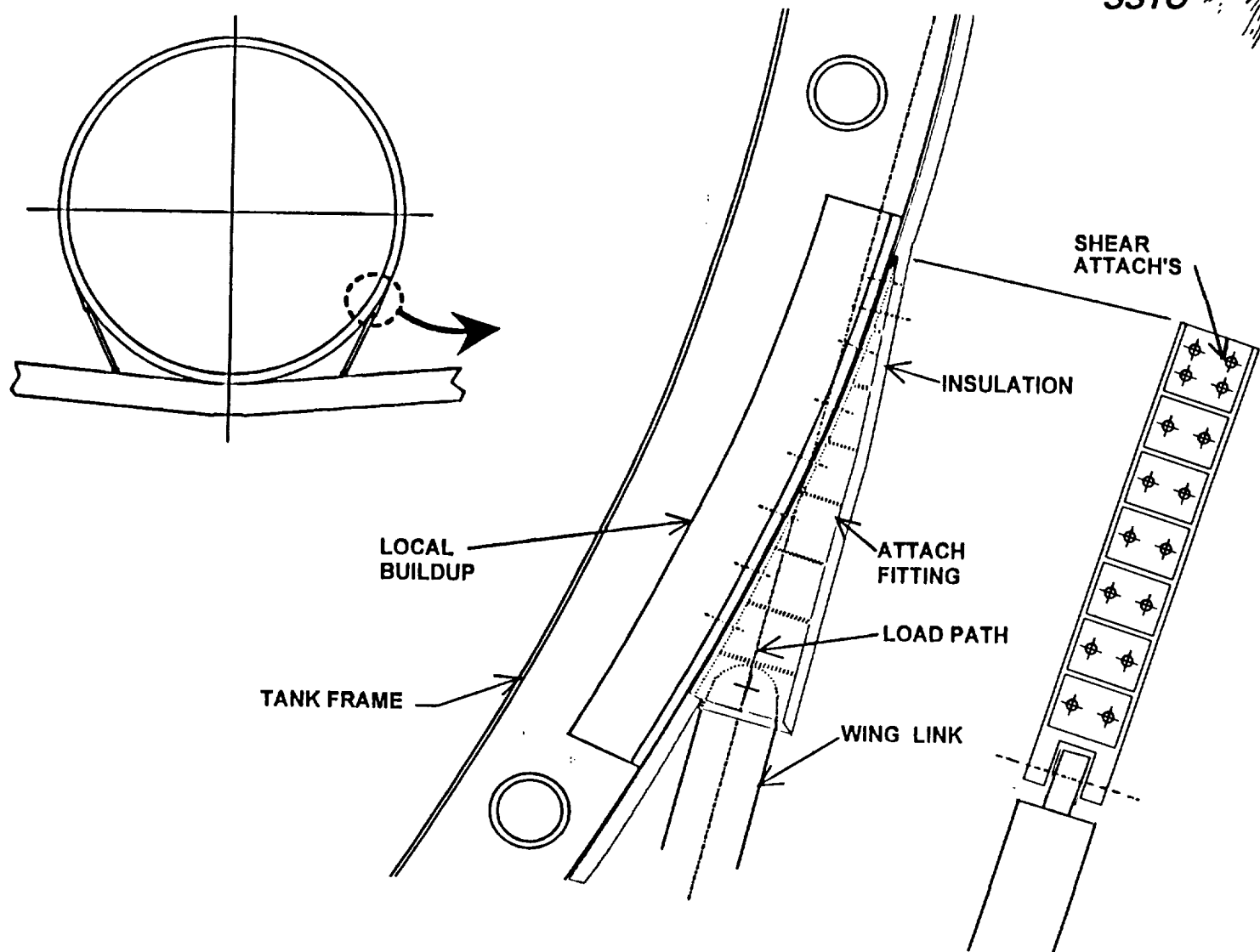
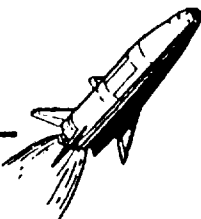


- Ascent TVC moment authority with single engine-out to:
 - Balance aerodynamic moment
 - Provide trajectory control
 - Provide dynamic stability
 - Remove errors from C. G. tracking, engine installation, thrust vector misalignment, aero- uncertainties, Nav & control sensors and actuator errors
- Projected angle-of-attack < 5 degrees for both configurations, assuming nominal is zero.
- Configuration 1A is marginal in control effectiveness for no engine-out and no system errors conditions. Pitch plane cg -tracking TVC gimbal angle is from 1.5 to 3.64 degrees. Trajectory and disturbance recovery require 4.2 degrees. Engine -out and other errors sources account for 1.5 degrees. Est. Max. is +/-7.5 degs. Actuation rate is at least 12 deg/sec.
- Configuration 2A is stable and controllable TVC gimbal requirement is within +/-6 degrees .

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

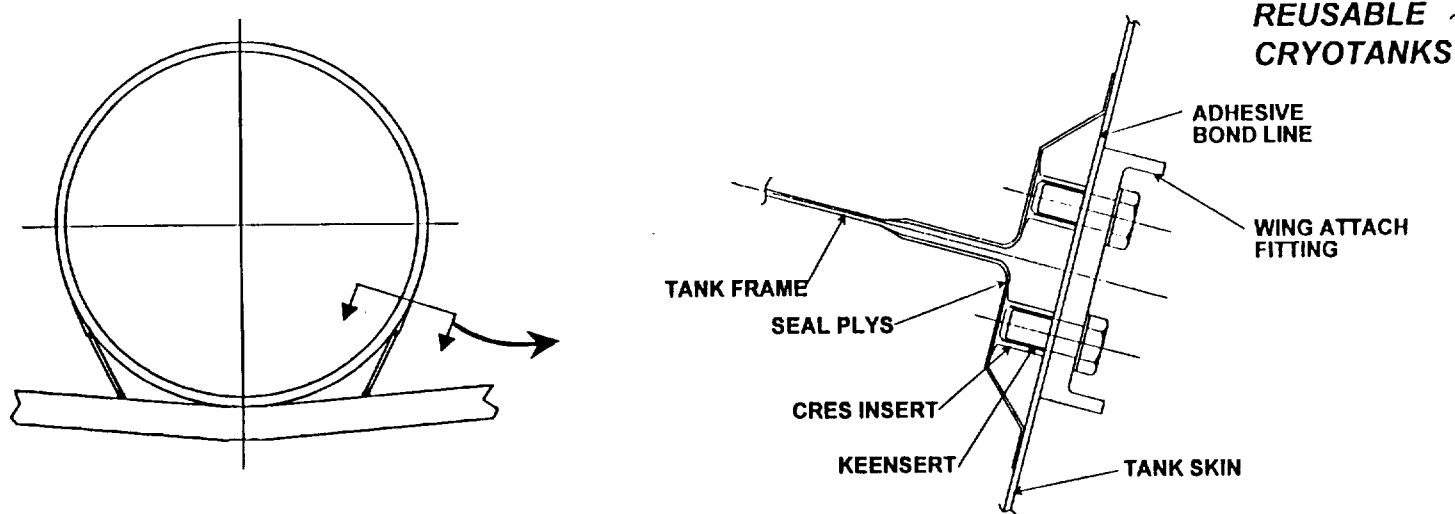
2A Wing Attach Shear Fitting Minimizes Normal Loads

SSTO



NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

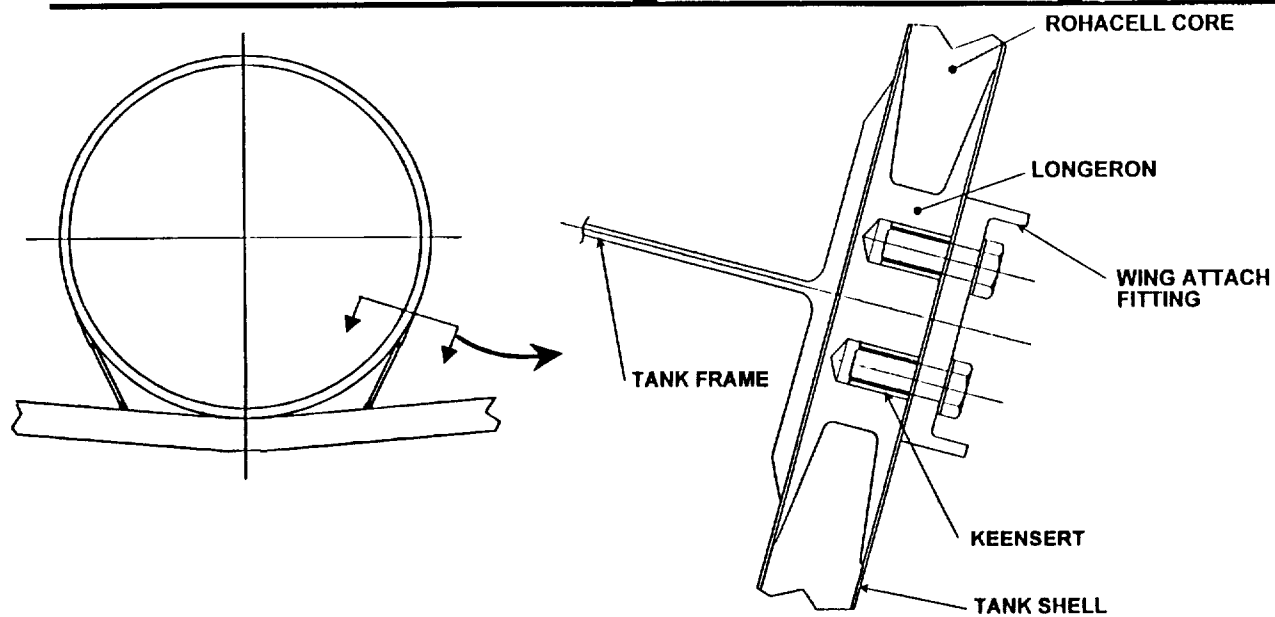
2A Wing Attachment to Skin-Stringer LH2 Tank Has High Design Risk



- Potential leak path in adhesive between frame & skin.
- Heavy frames at wing attachment causes high normal load between skin & frames - potential for bending induced adhesive peel failures in stringers.
- High transverse CTE of composite vs CRES presents potential for cracking around insert.
- Requires hand laying of seal plys after insert installed in frame.

NASA - ROCKWELL/SSD - ROCKWELL/NAAD/TULSA - HERCULES

2A Wing Attachment to Sandwich Tank Has High Design Risk But Reduced Mfg. Risk & Leakage Potential



- Heavy frames at wing attachment causes high radials load between skin & frames - potential for frame flange peel
- Wing fitting attaches to longeron imbedded in sandwich; design adequacy depends on load shearing from longeron to inner facesheet and thru adhesive to frame cap
- No penetrations of inner face - no leakpaths (for concept shown)
- Improved producibility over skin-stringer design

NASA - ROCKWELL/SSD - ROCKWELL/NAAD/TULSA - HERCULES

2A Option Represents High LH Tank Structural Design Risk

SSTO



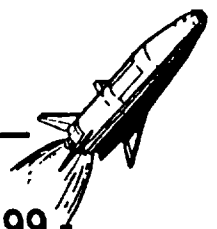
- Wing attachment to LH tank avoids weight penalty of long glove to avoid tank
- Wing attachment to tank presents significant potential leakage concern and high radial tension loads across cobonded skin to frame interface (838 lb/in instead of 300 lb/in for 1A design)
- Wing attachment fitting loads result in cross ply tension loads- worst loading for composites
- Numerous wing to tank attachments reduce cross ply tension loads but represent increased heat shorts
- All the above is significant risk in view of current LH tank development schedule
- Alternative to avoid attachment to LH tank represents 228,900 gross vehicle weight penalty

Proceed with technology development to 1A option - Avoid wing attachment design pending completion of control analyses by March 27, 1995

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Non-integral Tank May Be Most Likely Design for Strict Adherence to Debris Impact - Lowest Risk Design

SSTO



No option satisfies no penetration probability requirement in regime of .99
Current weight penalty of non-integral tank may be negated for strict adherence to this requirement

Advantages of non-Integral design are:

- Non-Integral tank - Loss of pressure is not expected to be critical to vehicle survival- burst pressure issue applies to both
- Cryogenic Insulation is not exposed to 400 F - Other Insulations possible
- Avoidance of criticality of Y-joint technology development

Technology development requirements of non-integral tank are enveloped by integral tank design

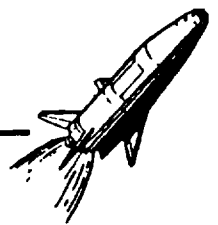
Designs to required debris impact have significant increases in skin thickness - reduced limit stresses, and radial tension loads

Recommendation - Do not include debris impact requirement into development of hydrogen tank - Pursue investigation of debris impact requirements and solutions

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES

Conclusions

SSTO



Option 1A (LH tank forward, integral tank, payload at midbody) is most suitable structural arrangement

- **Option 1A marginally controllable**
- **Option 2A stable and controllable**

Option 2A Wing attachment to composite LH tank has high design risk

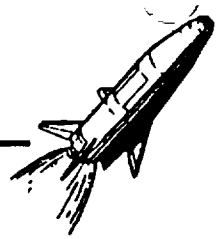
Common bulkhead designs represent prohibitive risk

Non integral tank can be most suitable design for strict adherence to current debris impact

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES
--

Development Recommendations

SSTO

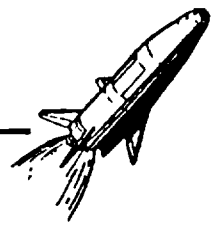


- Proceed with development of integral 1A Hydrogen tank - Development to encompass integral and non-integral LH tank

Above development is also applicable to 3A (with Intertank) Hydrogen tank and 1B-1 non-integral tank with short skirts (Avoidance of penetrations)

- Proceed with development of 1A Intertank - Lowest loads provide design with fabrication challenge
- Proceed with development of 1A Wing with supports straddling LO Tank
- Proceed with 1A Conical Shell Thrust Structure - will have highest gimbal forces
- In any future NRA composite LO tank efforts proceed with 1A LO tank development based on wing attachments straddling the LO tank
- Proceed with refinement of 1A Finite Element Model

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES



Stay with Gr/BMI unpressurized structures

Use of AFR 700 on Intertank, Wing, Wing control surfaces and Tail results in essentially the same gross vehicle weight as Gr/BMI for Space Station mission

Design to 1100 nm polar AOA will increase TPS weight with AFR 700 design

Operations reductions are small because of small reductions in TPS surface area

Use of TMC, and Blackglas protected by CSic TPS, as necessary, represented significant vehicle weight increase

CSic TPS repair, and replacement time savings are offset by increased inspection and waterproofing hours

All material variations from Gr/BMI with blanket TPS represent TA 2 schedule risk

NASA - ROCKWELL/SSD - NORTHROP/GRUMMAN - ROCKWELL/NAAD/TULSA - HERCULES
